US009497901B2

(12) **United States Patent**
Willgert

(10) **Patent No.: US 9,497,901 B2**
(45) **Date of Patent: Nov. 22, 2016**

(54) **BOUNDARY DEFINITION SYSTEM FOR A ROBOTIC VEHICLE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/420,963**

(22) PCT Filed: **Aug. 12, 2013**

(86) PCT No.: **PCT/SE2013/050965**

§ 371 (c)(1),
(2) Date: **Feb. 11, 2015**

(87) PCT Pub. No.: **WO2014/027946**

PCT Pub. Date: **Feb. 20, 2014**

(65) **Prior Publication Data**

US 2015/0201555 A1 Jul. 23, 2015

Related U.S. Application Data

(60) Provisional application No. 61/682,845, filed on Aug. 14, 2012.

(51) **Int. Cl.**
G05D 1/00 (2006.01)
B25J 5/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A01D 34/008*** (2013.01); ***G05D 1/0221*** (2013.01); ***G05D 1/0246*** (2013.01); ***G05D 1/0274*** (2013.01); *G05D 2201/0208* (2013.01)

(58) **Field of Classification Search**
CPC A01D 34/008; A01D 2101/00; G05D 1/0265; G05D 2201/0215; G05D
(Continued)

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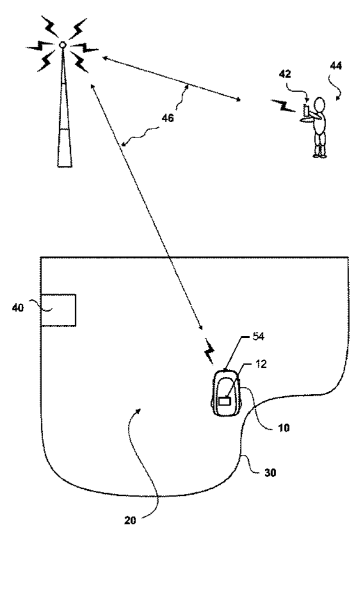
(57) **ABSTRACT**

A method for defining boundaries for a work area of a robotic vehicle may include receiving map data descriptive of a parcel of land and receiving information indicative of at least one reference object disposed on the parcel. The at least one reference object may have corresponding information for defining boundaries for a work area on the parcel associated therewith. The work area may define an area to be worked by a robotic vehicle. The method may further include determining the boundaries responsive to detection of the at least one reference object, and operating the robotic vehicle to remain within the area defined by the boundaries.

18 Claims, 7 Drawing Sheets



(51) **Int. Cl.**
G06F 19/00 (2011.01)
A01D 34/00 (2006.01)
G05D 1/02 (2006.01)

(58) **Field of Classification Search**
CPC 1/0214;G05D 1/0246; G05D 1/0274; G05D 2201/0208; Y10S 901/01; Y10S 56/07; A47L 2201/00; A47L 2201/04; B25J 9/0003; H04B 2203/5458; H04B 3/54
USPC 701/26; 318/568.1–568.2; 700/245, 700/243, 248, 261
See application file for complete search history.

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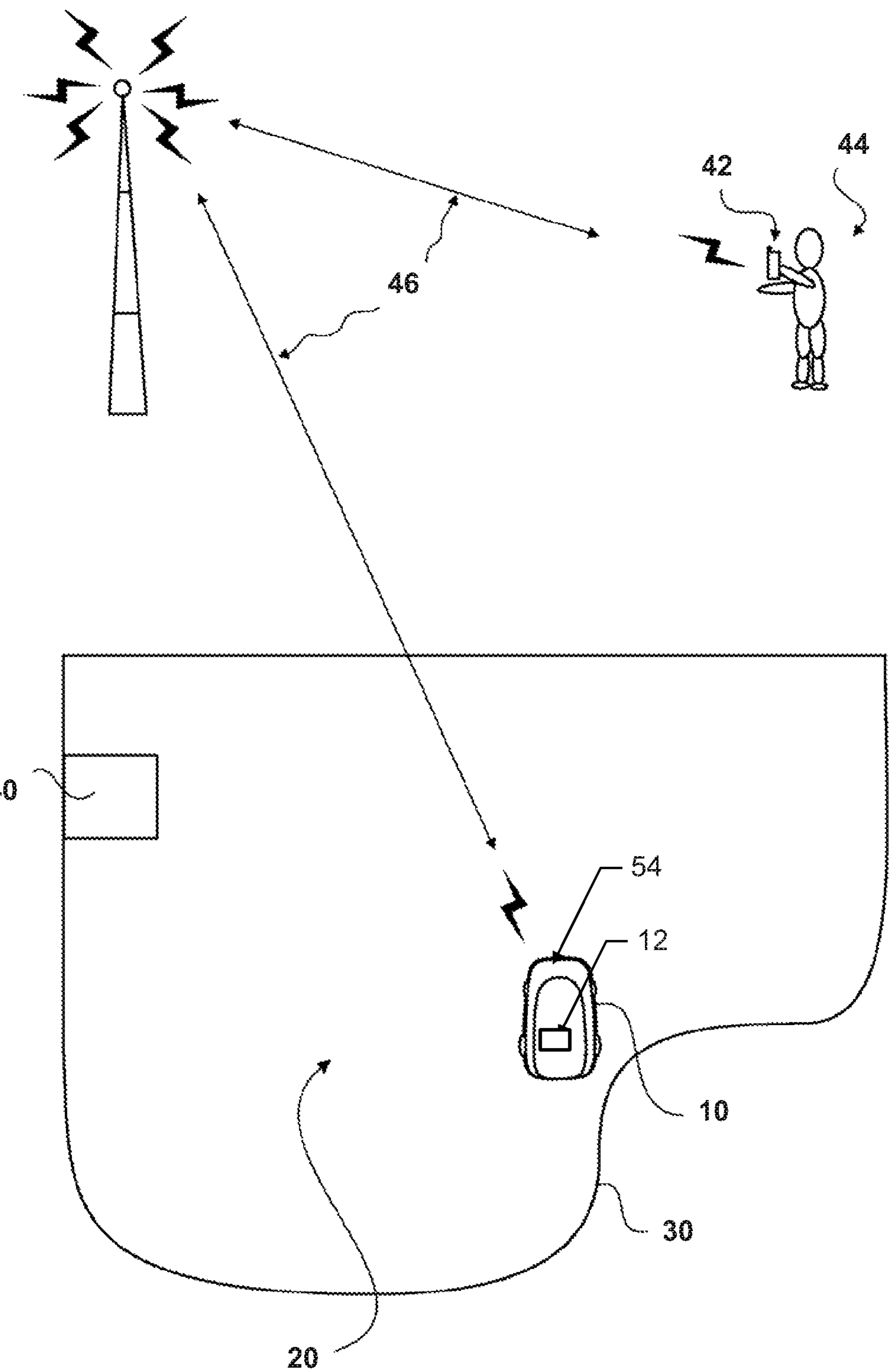

FIG. 1.

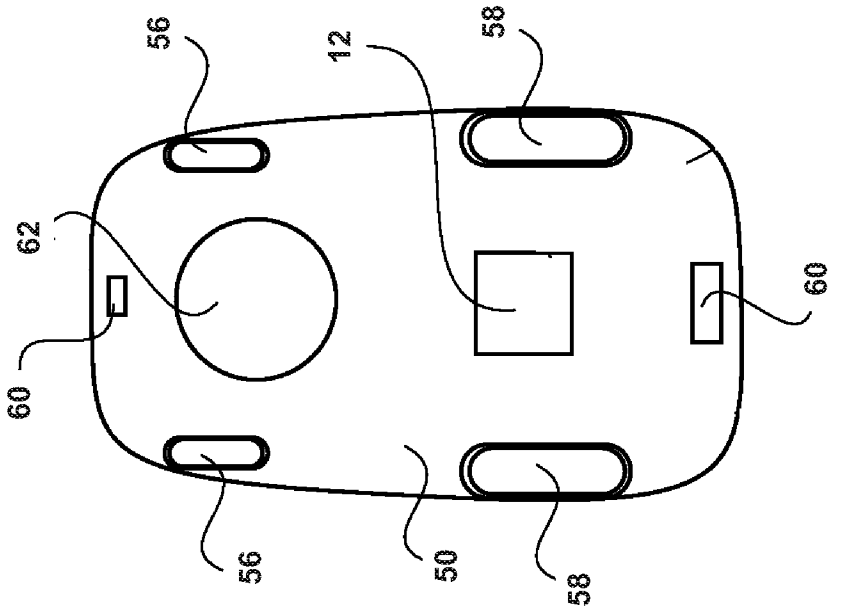

FIG. 2A.

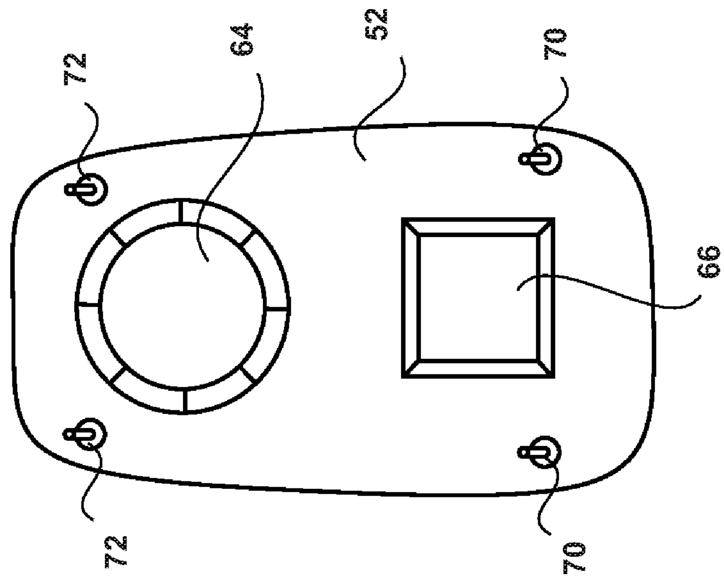

FIG. 2B.

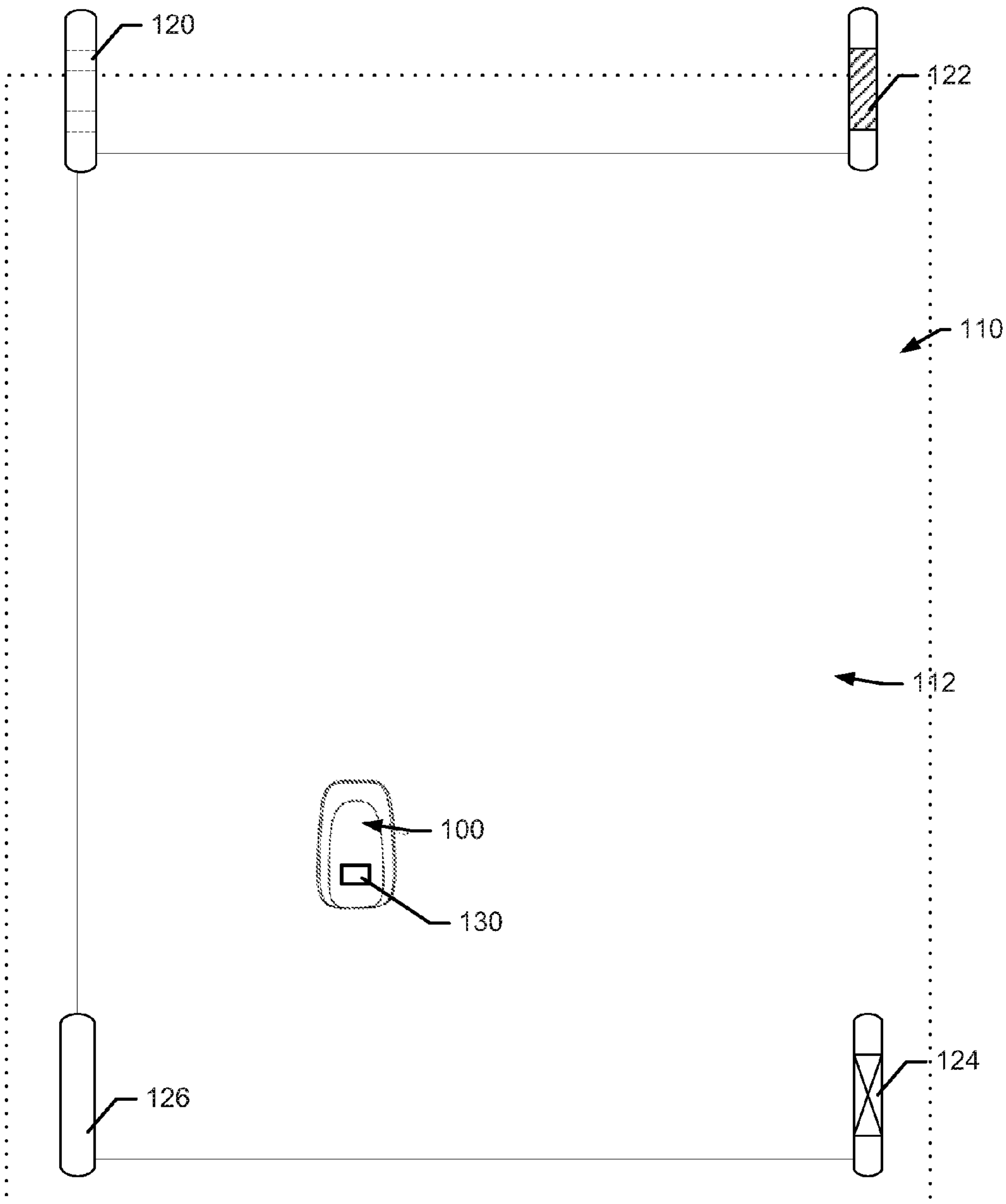

FIG. 3.

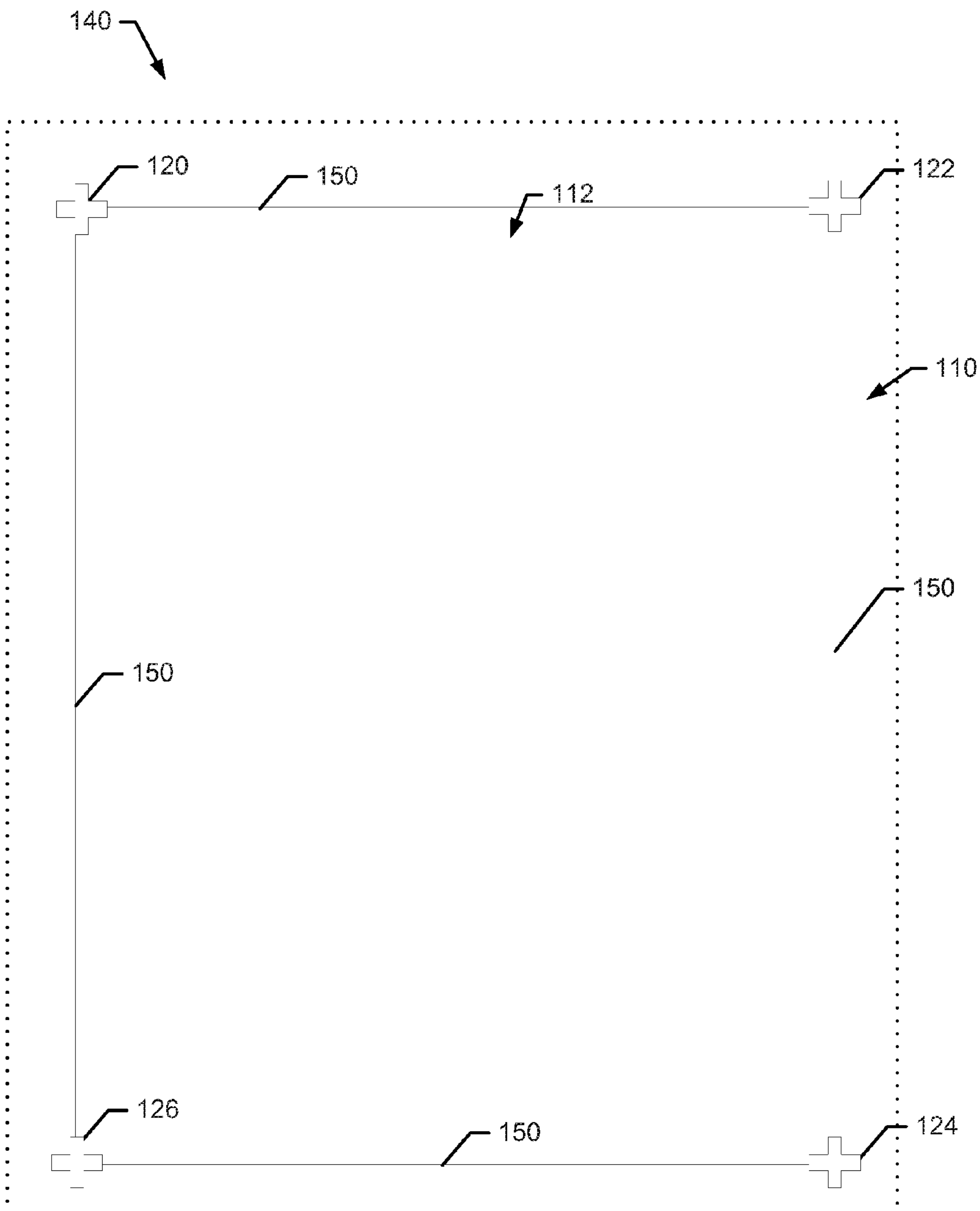

FIG. 4.

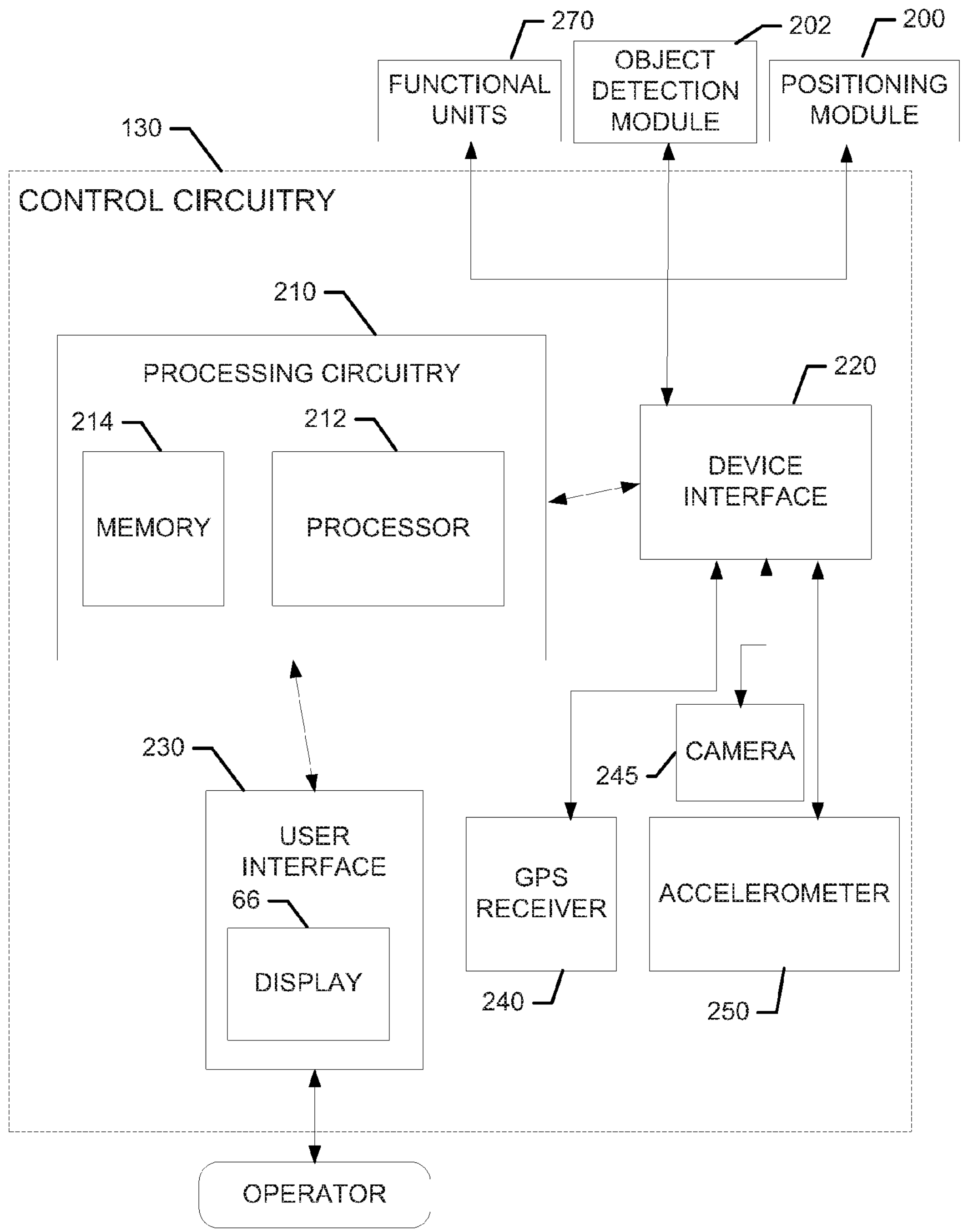
270
202
200
FUNCTIONAL UNITS
OBJECT DETECTION MODULE
POSITIONING MODULE
130
CONTROL CIRCUITRY
210
PROCESSING CIRCUITRY
214
212
MEMORY
PROCESSOR
220
DEVICE INTERFACE
230
USER INTERFACE
66
DISPLAY
245
CAMERA
GPS RECEIVER
ACCELEROMETER
240
250
OPERATOR

FIG. 5.

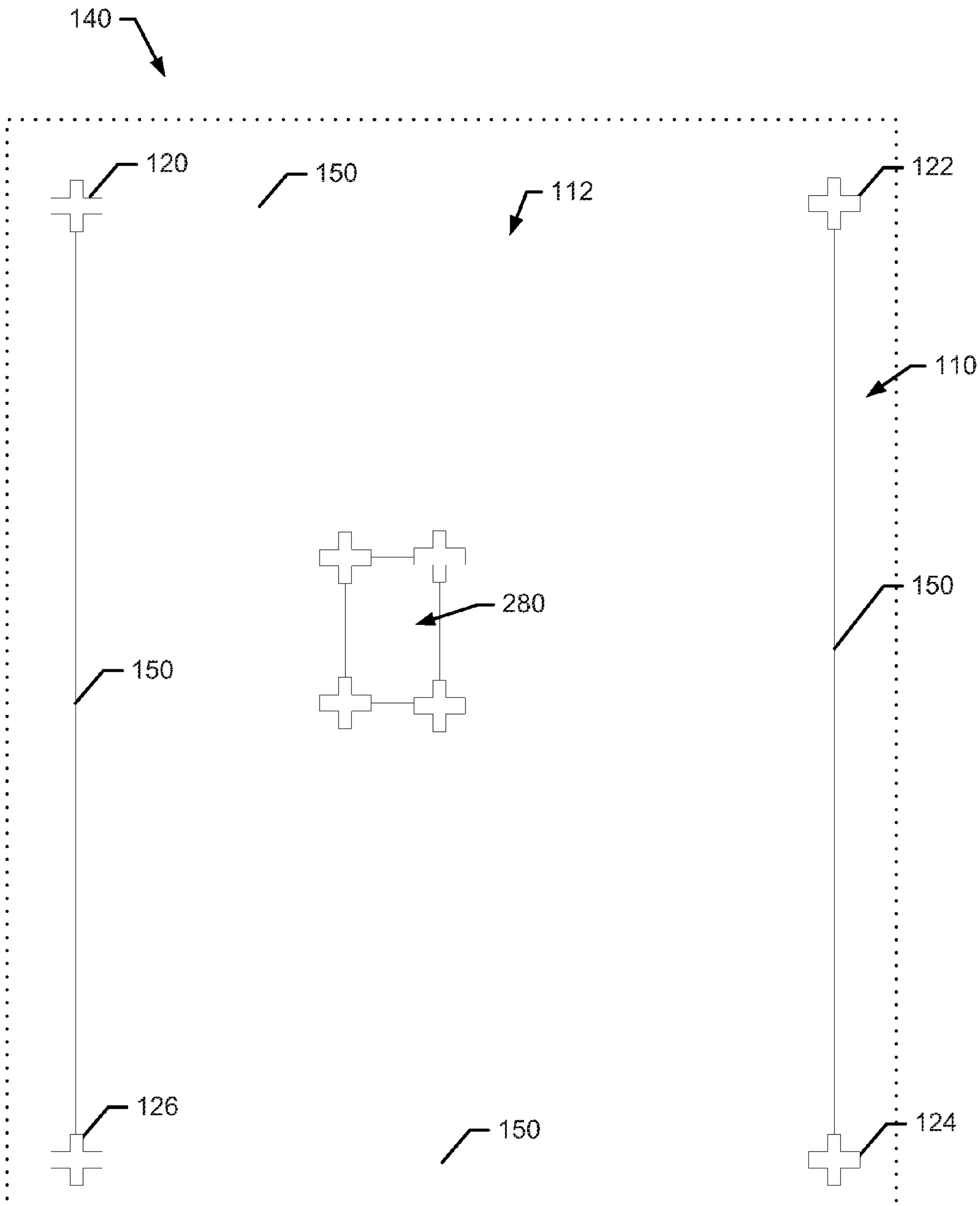

FIG. 6.

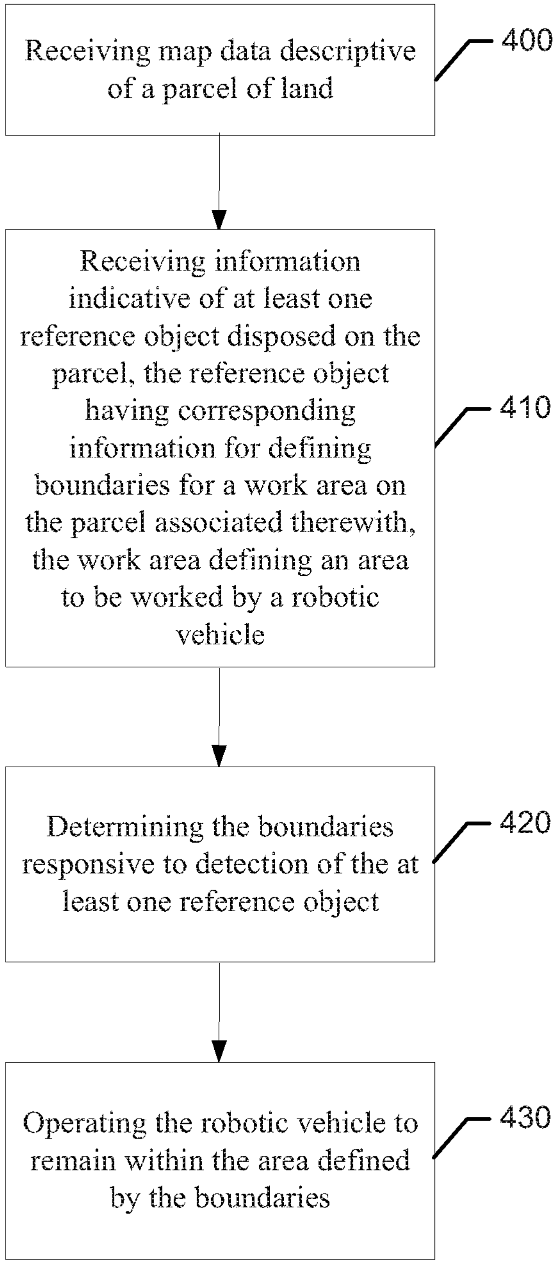
Receiving map data descriptive of a parcel of land
400
Receiving information indicative of at least one reference object disposed on the parcel, the reference object having corresponding information for defining boundaries for a work area on the parcel associated therewith, the work area defining an area to be worked by a robotic vehicle
410
Determining the boundaries responsive to detection of the at least one reference object
420
Operating the robotic vehicle to remain within the area defined by the boundaries
430

FIG. 7.

BOUNDARY DEFINITION SYSTEM FOR A ROBOTIC VEHICLE

TECHNICAL FIELD

Example embodiments generally relate to mowing devices and, more particularly, relate to a robotic vehicle that is configurable to operate within an area that is definable without the use of physical boundaries or cable detection.

BACKGROUND

Yard maintenance tasks are commonly performed using various tools and/or machines that are configured for the performance of corresponding specific tasks. Certain tasks, like grass cutting, are typically performed by lawn mowers. Lawn mowers themselves may have many different configurations to support the needs and budgets of consumers. Walk-behind lawn mowers are typically compact, have comparatively small engines and are relatively inexpensive. Meanwhile, at the other end of the spectrum, riding lawn mowers, such as lawn tractors, can be quite large. More recently, robotic mowers and/or remote controlled mowers have also become options for consumers to consider.

Lawn mowers are typically capable of transiting over even and uneven terrain to execute yard maintenance activities relating to mowing. However, most lawn mowers are repeatedly exposed to the same operating environments over the course of their lifetimes. For example, a lawn mower may operate to cut a single yard over its entire life, or may operate to cut a relatively fixed series of yards or parcels if it is used for commercial purposes. Given that computing devices are becoming more ubiquitous, it is to be expected that they may be employed to assist in operation of lawn mowers. As such, many additional functionalities may be provided or supported by the employment of computing devices on lawn mowers.

BRIEF SUMMARY OF SOME EXAMPLES

Some example embodiments may therefore provide a lawn mowing device having an onboard vehicle positioning module that may be configured to reference a map that is associated with the parcel being currently worked. The map may include defined boundaries for operation of the device where the boundaries are defined relative to known locations of one or more reference objects that are detectable via an object detection module.

In an example embodiment, a method for defining boundaries for a work area of a robotic vehicle may be provided. The method may include receiving map data descriptive of a parcel of land and receiving information indicative of at least one reference object disposed on the parcel. The at least one reference object may have corresponding information for defining boundaries for a work area on the parcel associated therewith. The work area may define an area to be worked by a robotic vehicle. The method may further include determining the boundaries responsive to detection of the at least one reference object, and operating the robotic vehicle to remain within the area defined by the boundaries.

According to another example embodiment, a robotic vehicle is provided. The robotic vehicle may include processing circuitry configured to receive map data descriptive of a parcel of land and receive information indicative of at least one reference object disposed on the parcel. The at least one reference object may have corresponding information for defining boundaries for a work area on the parcel associated therewith. The work area may define an area to be worked by the robotic vehicle. The processing circuitry may be further configured to determine the boundaries responsive to detection of the at least one reference object, and operate the robotic vehicle to remain within the area defined by the boundaries.

Some example embodiments may improve the ability of operators and/or fleet managers to make lawn mowers operate safely and/or efficiently.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** illustrates an example operating environment for a robotic mower;

FIG. **2**A illustrates a schematic view of a base plate and various components of the robotic mower according to an example embodiment;

FIG. **2**B illustrates a schematic view of an inner housing and various other components of the robotic mower according to an example embodiment;

FIG. **3** illustrates an example operating environment for a robotic mower that may employ an example embodiment;

FIG. **4** illustrates an example of map data that may be defined to represent all or a portion of the parcel according to an example embodiment;

FIG. **5** illustrates a block diagram of various components of processing circuitry of the robotic mower to illustrate some of the components that enable the functional performance of the robotic mower and to facilitate description of an example embodiment;

FIG. **6** illustrates an example in which an exclusion area is defined by a second set of reference objects located fully within a work area according to an example embodiment; and

FIG. **7** illustrates a block diagram of a method according to an example embodiment.

DETAILED DESCRIPTION

Some example embodiments now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all example embodiments are shown. Indeed, the examples described and pictured herein should not be construed as being limiting as to the scope, applicability or configuration of the present disclosure. Rather, these example embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like reference numerals refer to like elements throughout. Furthermore, as used herein, the term "or" is to be interpreted as a logical operator that results in true whenever one or more of its operands are true. Additionally, the term "yard maintenance" is meant to relate to any outdoor grounds improvement or maintenance related activity and need not specifically apply to activities directly tied to grass, turf or sod care. As used herein, operable coupling should be understood to relate to direct or indirect connection that, in either case, enables functional interconnection of components that are operably coupled to each other.

Robotic mowers typically mow an area that is defined by a boundary wire that bounds the area to be mowed. The robotic mower than roams within the bounded area to ensure that the entire area is mowed, but the robotic mower does not go outside of the bounded area. FIG. **1** illustrates an example operating environment for a robotic mower **10** that may employ a system bounded by such a boundary wire. The robotic mower **10** may operate to cut grass on a parcel **20** (i.e., a land lot), the boundaries of which may be defined using one or more physical boundaries (e.g., a fence, wall, curb and/or the like), a boundary wire **30** or combinations thereof. The boundary wire **30** may emit electrical signals that are detectable by the robotic mower **10** to inform the robotic mower **10** when a boundary of the parcel **20** has been reached. The robotic mower **10** may be controlled, at least in part, via control circuitry **12** located onboard. The control circuitry **12** may include, among other things, the ability to detect the boundary wire **30** to redirect the robotic mower **10** to other areas within the parcel **20**.

In an example embodiment, the robotic mower **10** may be battery powered via one or more rechargeable batteries. Accordingly, the robotic mower **10** may be configured to return to a charge station **40** that may be located at some position on the parcel **20** in order to recharge the batteries. The batteries may power a drive system and a blade control system of the robotic mower **10**. However, the control circuitry **12** of the robotic mower **10** may selectively control the application of power or other control signals to the drive system and/or the blade control system to direct the operation of the drive system and/or blade control system. Accordingly, movement of the robotic mower **10** over the parcel **20** may be controlled by the control circuitry in a manner that enables the robotic mower **10** to systematically traverse the parcel while operating a cutting blade to cut the grass on the work area of the parcel **20**.

In some embodiments, the control circuitry **12** may be configured to communicate wirelessly with an electronic device **42** (e.g., a computer, mobile telephone, PDA, smart phone, and/or the like) of a remote operator **44** via a wireless communication network **46**. However, the wireless network **46** and other remote devices may not be employed in some embodiments. The wireless network **46** may be a data network, such as a local area network (LAN), a metropolitan area network (MAN), a wide area network (WAN) (e.g., the Internet), and/or the like, which may couple the robotic mower **10** to devices such as processing elements (e.g., personal computers, server computers or the like) or databases. Communication between the wireless network **46** and the devices or databases (e.g., servers, electronic device **42**, control circuitry **12**) may be accomplished by either wireline or wireless communication mechanisms and corresponding protocols.

FIG. **2**, which includes FIGS. **2**A and **2**B, illustrates some of the parts that may be employed in connection with an example of the robotic mower **10**. However, it should be appreciated that example embodiments may be employed on numerous other vehicles that may employ different designs. FIG. **2**A illustrates a schematic view of a base plate and various components of the robotic mower according to an example embodiment and FIG. **2**B illustrates a schematic view of an inner housing and various other components of the robotic mower according to an example embodiment.

Referring to FIGS. **1** and **2**, the robotic mower **10** may include a base plate **50**, an inner housing **52** and an outer housing **54**. The inner housing **52** may be configured to be arranged on top of the base plate **50** and the outer housing **54** may be configured to be arranged on top of the inner housing **52**. The base plate **50** may form a support structure from which one or more front wheels **56** and one or more rear wheels **58** may be supported. In some embodiments, the one or more rear wheels **58** may be relatively large as compared to the one or more front wheels **56**. Moreover, the one or more rear wheels **58** may be configured to operate either in a forward or backward direction, but may otherwise not be steerable. However, the one or more front wheels **56** may be steerable responsive to control by the control circuitry **12**. Alternatively, the front wheels **56** may be swivel wheels capable of following any direction as required by the control of the rear wheels **58**.

In an example embodiment, the base plate **50** may further include one or more sensors **60** that may be used to detect the boundary wire **30** and/or objects that may form part of the boundary of the parcel. The sensors **60** may also detect objects that may be encountered during operation of the robotic mower **10** within the boundaries of the parcel **20**. These objects may be fixed or temporary (e.g., movable) objects. In some cases, the sensors **60** may include a front sensor and a rear sensor. However, it should be appreciated that any number of sensors may be employed and they may be disposed at any desirable location on the robotic mower **10**. The sensors **60** may include sensors related to positional determination (e.g., a GPS receiver, an accelerometer, a camera, a radar transmitter/detector, an ultrasonic sensor, a laser scanner and/or the like). Thus, for example, positional determinations may be made using GPS, inertial navigation, optical flow, radio navigation, visual location (e.g., VSLAM) and/or other positioning techniques or combinations thereof. Accordingly, the sensors **60** may be used, at least in part, for determining the location of the robotic mower **10** relative to boundaries or other points of interest (e.g., a starting point or other key features) of the parcel **20**, or determining a position history or track of the robotic mower **10** over time.

The base plate **50** may further support a cutting motor **62** configured to drive a cutting blade or other cutters of the robotic mower **10**. In some embodiments, the outer housing **54** and the inner housing **52** may be plastic, light metal, or other similarly lightweight components. The inner housing **52** may include a cover **64** for the cutting motor **62**. In some embodiments, a user interface (e.g., display **66**) may be provided on the inner housing **3**. The user interface may be employed to interface with the control circuitry **12** for controlling operations of the robotic mower **10**.

In some embodiments, the sensors **60** may include sensors specifically provided for detecting objects (other than the boundary wire **30** or objects forming boundaries of the parcel **20**) and/or sensors for detecting lifting (or tipping beyond a threshold amount) of the robotic mower **10**. Alternatively, separate sensors (e.g., collision sensors **70** and lifting sensors **72**) may be provided for each function, and those sensors may be capable of communicating with the control circuitry **12** in addition to the sensors **60**. In an example embodiment, the sensors **60** may include a camera, which may be used to optically determine the existence of objects in view of the camera and, in some embodiments, may be configured to determine or distinguish an identity of the object (e.g., to determine if an object is a reference object).

The type of work area definition described above tends to work well for many users. However, some users may find installation of the boundary wire **30** to be a relatively difficult and time consuming task. Furthermore, if the boundary wire **30** is damaged, it may be relatively difficult to repair. Additionally, both the initial cost of the boundary wire **30**, and any replacement cost that might be encountered if the boundary wire **30** is destroyed, add to the overall cost of the system. Thus, it may be advantageous to define the work area by another mechanism that is less costly and less work intensive.

Some example embodiments may therefore be provided that enable a work area to be defined relative to map data indicative of the parcel. Accordingly, for example, one or more reference points may be defined on the map and boundaries for the work area may be defined in relation to the one or more reference points. The robotic mower may therefore identify a reference point. The robotic mower may further be enabled to determine its position relative to the reference point and boundaries that are defined relative to the reference point based on tracking its position relative to the map data. Accordingly, with potentially less physical effort and less cost, the bounded area in which the robotic mower is to work may be reliably defined.

Other robotic vehicles (e.g., a robotic watering vehicle) may operate in similarly defined areas, but an example embodiment will be described herein in connection with a robotic mower. However, it should be appreciated that example embodiments are not limited to application only on robotic mowers. Instead, example embodiments may also be practiced in connection with other robotic vehicles that operate within bounded regions.

In an example embodiment, a robotic vehicle (e.g., a remote-controlled or autonomously operable robotic mower, watering robot, and/or the like) is provided with an onboard positioning module and an object detection module. The positioning module may be configured to enable data related to position and/or orientation information regarding the vehicle to be tracked and/or recorded. The position and/or orientation information may then be stored and/or processed (e.g., by onboard or remote processing and storage equipment) to generate or augment map data associated with a parcel being worked. The map data may include defined boundaries for operation of the vehicle and may also define the location of reference objects located within (or at edges of) the boundaries, where the reference objects are used as points of reference from which the boundaries are defined using the map data. The object detection module may be configured to detect objects encountered by the device during operation on within the boundaries. Responsive to detection of an object that corresponds to a reference object, the object detection module may be configured to inform the positioning module of the detection so that the positioning module can be used in connection with the object detection module for determining a position of a boundary relative to the reference object. The robotic vehicle may then be steered or otherwise operated accordingly. In this regard, for example, the robotic vehicle may be steered away when any boundary is reached.

Additionally or alternatively, some embodiments may be employed to provide feedback, warnings, or even implement automatic functionality (e.g., stopping blade rotation and/or stopping drive power application) responsive to detection of movement outside of the bounded area.

FIG. **3** illustrates an example environment in which the robotic mower **100** of an example embodiment may operate. The robotic mower **100** may be battery powered, as described above, and may charge at a charging station and also have the communication capabilities described above. The robotic mower **100** may also include similar sensors and other structural components to those described above. As shown in FIG. **3**, a parcel **110** may include a plurality of reference objects (e.g., a first reference object **120**, a second reference object **122**, a third reference object **124** and a fourth reference object **126**). The reference objects may, in this example, be positioned at four corners of a rectangular shaped region on the parcel **110** to define a work area **112**. However, it should be appreciated that the reference objects could be positioned to define any desirable shape, and that the reference objects need not necessarily be positioned at corners or even edges of the parcel **110**. It should also be noted that although the reference objects are each shown as posts or stakes that have uniquely different markings thereon, it is not necessary that reference objects include any markings at all, much less distinct markings. However, some embodiments may employ identifying indicia, so that the robotic mower **100** can determine which specific reference object is being encountered at any given time.

In an example embodiment, the robotic mower **100** may include control circuitry **130** that is used to control operation of the robotic mower **100** (e.g., direction and/or speed of movement, blade rotation, and/or the like). The robotic mower **100** may further include a positioning module and an object detection module (each of which will be described in greater detail below), which operate with or under control of the control circuitry **130**. Accordingly, the robotic mower **100** may utilize the control circuitry **130** to define map data **140** indicative of the work area **112** on the parcel **110** in terms of defining the boundaries of the work area and/or the location of reference objects thereon. FIG. **4** illustrates an example of map data **140** that may be defined to represent all or a portion of the parcel **110**. As seen in FIG. **4**, the map data **140** may include recorded positions of the reference objects (represented schematically as generic crosses in FIG. **4**). The map data **140** may further define boundaries **150** relative to the positions of the reference objects.

It should be appreciated that although the boundaries **150** are defined as discrete segments that extend between individual ones of the reference objects (e.g., a first segment extending between the first reference object **120** and the second reference object **122**, a second segment extending between the second reference object **122** and the third reference object **124**, a third segment extending between the third reference object **124** and the fourth reference object **126**, and a fourth segment extending between the fourth reference object **126** and the first reference object **120**), segments of the boundaries **150** need not extend between two reference objects, or even extend from a single reference object. Instead, boundaries **150** may be defined relative to one or more reference objects (e.g., based on a distance and direction from a reference object, or based on a range of distances over a corresponding range of directions from the reference object). However, in some embodiments, regardless of how the boundaries **150** are defined, the boundaries **150** may form a continuous peripheral limit for a work area of the robotic mower **100**.

FIG. **5** illustrates a block diagram of various components of the control circuitry **130** to illustrate some of the components that enable the functional performance of the robotic mower **100** and to facilitate description of an example embodiment. In some example embodiments, the control circuitry **130** may include or otherwise be in communication with positioning module **200** and an object detection module **202** disposed at the robotic mower **100**. As such, for example, the functions attributable to the positioning module **200** and/or the object detection module **202** may be carried out by the control circuitry **130**.

The control circuitry **130** may include processing circuitry **210** that may be configured to perform data processing, control function execution and/or other processing and management services according to an example embodiment of the present invention. In some embodiments, the processing circuitry **210** may be embodied as a chip or chip set. In other words, the processing circuitry **210** may comprise one or more physical packages (e.g., chips) including materials, components and/or wires on a structural assembly (e.g., a baseboard). The structural assembly may provide physical strength, conservation of size, and/or limitation of electrical interaction for component circuitry included thereon. The processing circuitry **210** may therefore, in some cases, be configured to implement an embodiment of the present invention on a single chip or as a single "system on a chip." As such, in some cases, a chip or chipset may constitute means for performing one or more operations for providing the functionalities described herein.

In an example embodiment, the processing circuitry **210** may include one or more instances of a processor **212** and memory **214** that may be in communication with or otherwise control a device interface **220** and, in some cases, a user interface **230** (e.g., display **66**). As such, the processing circuitry **210** may be embodied as a circuit chip (e.g., an integrated circuit chip) configured (e.g., with hardware, software or a combination of hardware and software) to perform operations described herein. However, in some embodiments, the processing circuitry **210** may be embodied as a portion of an on-board computer. In some embodiments, the processing circuitry **210** may communicate with electronic components and/or sensors (e.g., sensors **60**, collision sensors **70** and/or lifting sensors **72**) of the robotic mower **100** via a single data bus. As such, the data bus may connect to a plurality or all of the switching components and/or other electrically controlled components of the robotic mower **100**.

The user interface **230** (if implemented) may be in communication with the processing circuitry **210** to receive an indication of a user input at the user interface **230** and/or to provide an audible, visual, mechanical or other output to the user. As such, the user interface **230** may include, for example, a display (e.g., display **66**), one or more buttons or keys (e.g., function buttons), and/or other input/output mechanisms (e.g., microphone, speakers, cursor, joystick, lights and/or the like).

The device interface **220** may include one or more interface mechanisms for enabling communication with other devices (e.g., sensors of a sensor network including sensors **60**, collision sensors **70** and/or lifting sensors **72** and/or other accessories or functional units **270** such as motors, servos, switches or other operational control devices for automatic responses). In some cases, the device interface **220** may be any means such as a device or circuitry embodied in either hardware, or a combination of hardware and software that is configured to receive and/or transmit data from/to sensors in communication with the processing circuitry **210**. In some example embodiments, the device interface **220** may provide interfaces for communication of components internal to the positioning module **200** and/or the object detection module **202** (as shown in the example of FIG. **5**). However, in other embodiments, components of the sensor network (e.g., including GPS receiver **240**, camera **245**, and/or accelerometer **250**) may be external to the positioning module **200** and the object detection module **202**, and the device interface **220** may still provide interface capabilities for interaction with such components. Automatic responses such as operational control functions that implement automatic actions to be taken responsive to detection of certain stimuli may also be provided via the device interface **220**. For example, shutdown of the cutting motor **62** (e.g., responsive to tipping or lifting of the robotic mower **10**), stopping movement or changing direction of the robotic mower **100** (e.g., responsive to encountering an object or boundary) may be initiated under control of the processing circuitry **210** via interfaces provided by the device interface **220**. Additionally or alternatively, interactions implemented via the provision of control signals to the functional units **270** may be initiated via the device interface **220**.

In embodiments employing a sensor network, the sensor network may include one or more sensors (e.g., sensors **60** and/or collision sensors **70** and lifting sensors **72**) disposed at any of various locations on the robotic mower **100** to monitor various parameters. For example, one or more sensors may determine vehicle speed/direction, vehicle location, object presence, vehicle orientation and/or the like. Sensors may also be used to determine motor run time, machine work time, and other operational parameters. In some embodiments, positioning and/or orientation sensors (e.g., global positioning system (GPS) receiver **240** and/or accelerometer **250**) may be included to monitor, display and/or record data regarding vehicle position and/or orientation. In this regard, for example, the GPS receiver **240** may be configured to generate map data corresponding to latitude, longitude, speed, elevation, time, data and/or the like of the riding yard maintenance vehicle **10**, and communicate such data to the processing circuitry **210**. Meanwhile, for example, the accelerometer **250** may be configured to generate data corresponding to horizontal, vertical, and rotational accelerations of the riding yard maintenance vehicle **10**, and communicate such data to the processing circuitry **210**. As such, information such as pitch angle, roll angle and yaw angle may be determinable using one or more sensors of the sensor network. Moreover, distance and/or direction from a particular point of reference may be determined. Data from the sensors (including the data from the GPS receiver **240**, the accelerometer **250** and/or other sensors) may be fed to the processing circuitry **210** for storage, display, or for use in connection with applications that may be executed by processing circuitry **210**.

The positioning module **200** may be configured to utilize one or more sensors (e.g., sensors **60**, which may include GPS receiver **240**, camera **245** and/or accelerometer **250**) to determine a location of the robotic mower **100**. The robotic mower **100** (or more specifically, the control circuitry **130**) may use the location information to determine a mower track and provide full coverage of the parcel **110** to ensure the entire parcel **110** is mowed. The positioning module **200** may therefore be configured to determine a location of the robotic mower **100** relative to the map data **140** descriptive of the parcel **110**.

The object detection module **202** may employ one or more sensors (e.g., sensors **60**, camera **245**, and/or collision sensors **70**) to determine when an object is detected. When an object is detected, the processing circuitry **210** may be informed so that the location of the robotic mower **100** at the time of detection of the detected object may be noted. Thus, when an indication is received from the object detection module **202** to inform the processing circuitry **210** that the detected object has been encountered, the processing circuitry **210** may access position information from the positioning module **200** to associate the detected object with the corresponding location. The processing circuitry **210** may further utilize the sensors (e.g., the GPS receiver **240**, camera **245** and/or accelerometer **250**) to attempt to determine an identity of the object encountered. For example, the processing circuitry **210** may utilize the GPS receiver **240** to determine whether the object is encountered at a location corresponding to the known location of a reference object, utilize the camera **245** to determine if the object visually matches a known image of a reference object, and/or utilize the accelerometer **250** to determine whether the object is located at a distance and/or direction from a reference object that matches a known distance and/or direction that a known reference object has from the reference object.

The processor **212** may be embodied in a number of different ways. For example, the processor **212** may be embodied as various processing means such as one or more of a microprocessor or other processing element, a coprocessor, a controller or various other computing or processing devices including integrated circuits such as, for example, an ASIC (application specific integrated circuit), an FPGA (field programmable gate array), or the like. In an example embodiment, the processor **212** may be configured to execute instructions stored in the memory **214** or otherwise accessible to the processor **212**. As such, whether configured by hardware or by a combination of hardware and software, the processor **212** may represent an entity (e.g., physically embodied in circuitry—in the form of processing circuitry **210**) capable of performing operations according to embodiments of the present invention while configured accordingly. Thus, for example, when the processor **212** is embodied as an ASIC, FPGA or the like, the processor **212** may be specifically configured hardware for conducting the operations described herein. Alternatively, as another example, when the processor **212** is embodied as an executor of software instructions, the instructions may specifically configure the processor **212** to perform the operations described herein.

In an example embodiment, the processor **212** (or the processing circuitry **210**) may be embodied as, include or otherwise control the positioning module **200** and the object detection module **202**. As such, in some embodiments, the processor **212** (or the processing circuitry **210**) may be said to cause each of the operations described in connection with the positioning module **200** and the object detection module **202** by directing the positioning module **200** and the object detection module **202**, respectively, to undertake the corresponding functionalities responsive to execution of instructions or algorithms configuring the processor **212** (or processing circuitry **210**) accordingly. As an example, the positioning module **200** may be configured to record position and/or orientation information of the robotic mower **100** and the object detection module **202** may be configured to record or otherwise identify interactions with objects as described herein. The processing circuitry **210** may then, in some cases, process the information from one or both of the positioning module **200** and the object detection module **202** to avoid objects, generate alerts, warnings, position histories, map data identifying known and/or unknown object locations, and/or the like.

In an exemplary embodiment, the memory **214** may include one or more non-transitory memory devices such as, for example, volatile and/or non-volatile memory that may be either fixed or removable. The memory **214** may be configured to store information, data, applications, instructions or the like for enabling the positioning module **200** and/or the object detection module **202** to carry out various functions in accordance with exemplary embodiments of the present invention. For example, the memory **214** could be configured to buffer input data for processing by the processor **212**. Additionally or alternatively, the memory **214** could be configured to store instructions for execution by the processor **212**. As yet another alternative, the memory **214** may include one or more databases that may store a variety of data sets responsive to input from the sensor network. Among the contents of the memory **214**, applications may be stored for execution by the processor **212** in order to carry out the functionality associated with each respective application. In some cases, the applications may include a comparison of information indicative of a detected object to stored information about the parcel **110** currently being worked in order to determine whether the detected object is a known object.

Thus, for example, the memory **214** may store a parcel descriptor file including map data **140** defining boundaries **150** of the parcel **110** and location information identifying any known (e.g., reference) objects on the parcel **110** along with their respective locations or identifying characteristics (e.g., GPS coordinates or distance/direction from another known location or position, or a reference image). When the detected object is encountered, the map data **140** of the parcel descriptor file may be accessed (via the processing circuitry **210**) to determine whether the detected object correlates to one of the reference objects on the parcel **110** via a comparison of the location of the detected object to the corresponding locations of known objects on the parcel **110** or via a comparison of a reference image to a current image. If a reference object on the parcel **110** is found to match the location of the detected object, the detected object may be determined (via the processing circuitry **210**) to be a corresponding one of the reference objects. Boundary positions may then be determined and the robotic mower **100** may be steered in a manner that keeps the robotic mower **100** within the work area **112**.

In some embodiments, the reference objects may be marked with unique, optically readable marks. Accordingly, for example, each unique mark may be identified and its position may be known on the map data **140**. The robotic mower **100** may then be further programmed to move relative to each known reference object in a particular manner to achieve complete coverage of the work area **112** without transiting outside of the work area **112**. In some cases, the work area **112** may be defined as a polygon, or as a series of adjacent or relatively nearby polygons, so that the robotic mower **110** may sequentially mow polygonal shaped work areas. The camera **245** may be used to identify or read unique markings and, in some cases, employ triangulation, stereo view, and/or the like to determine a location relative to the reference object **120**, **122**, **124**, **126**. Given the known location of the boundaries **150** relative to the reference objects, if the object can be determined as a reference object and the location of the robotic mower **100** can be determined relative to the reference object, then the position of the robotic mower **100** relative to the boundaries **150** can be determined. In some cases, the markings may be defined to indicate or represent a sequential ordering of the reference objects.

In some embodiments, exclusion areas (or islands) may further be defined within the work area **112**. For example, FIG. **6** shows an example in which an exclusion area **280** is defined by a second set of reference objects located fully within the work area **112**. Accordingly, information associated with the type of border that applies for each boundary (e.g., work area boundary or exclusion area boundary) may be stored in association with each reference object. Thus, when a reference object is encountered, it may be appreciated as to which borders it is useful in defining.

In an example embodiment, the processing circuitry **210** may be configured to record the locations of any and all reference objects and associate the locations with GPS coordinates. Thus, for example, the processing circuitry may be configured to "learn" the locations of the reference objects and therefore also "learn" the locations of the boundaries **150**. After learning the boundaries **150** in terms of GPS coordinates (or in terms of distance from a known starting point such as the charging station), the robotic mower **100** may simply operate within the work area **112** based on the learned information. Thus, for example, the reference objects themselves (all or a portion thereof) may be removed.

In some embodiments, rather than utilizing physical objects for the reference objects, a painted line or marking (visible or invisible) that can be detected by a sensor may be employed as an alternative. Other information about details regarding the map data **140** may also be stored in some embodiments. For example, information about fence location, gravel, concrete or paved path location, road location, object location (i.e., non-reference objects), and/or the like may also be stored in connection with the map data **140**.

In an example embodiment, the processing circuitry **210** may be configured to generate display views and/or screen emulations to display data gathered by the sensor network and/or to display information generated based on the data gathered by the sensor network either locally or remotely (responsive to communication of the information via a wireless network or via communication established at the charge station **40**. Alternatively or additionally, the processing circuitry **210** may be configured to generate reports or displays to illustrate information determinable based on the data. In some embodiments, the processing circuitry **210** may process, direct display of and/or store GPS position data (e.g., as a position history), speed information, information regarding object detection, map views, and/or the like. Thus, for example, the processing circuitry **210** may direct storage of the data or other information generated based on the data in the memory **214**. As such, the processing circuitry **210** may organize the data or information for reporting or for use in other applications that may be locally or remotely executed. For example, the processing circuitry **210** may store data for reporting to a computer executing fleet management software to manage a fleet of lawn mowers for implementation of efficient service, maintenance and operation management.

In some cases, information associated with the positioning module **200** and/or the object detection module **202** itself may be extracted from the robotic mower **10** and mated with a remote network terminal or computer. The information stored on the memory **214** may then be extracted and thereby reported for fleet management or other applications. In other cases, the device interface **220** may be configured to wirelessly transmit information associated with the positioning module **200** and/or the object detection module **202** to a remote computer to enable data processing to be accomplished on the remote computer. For example, in some cases, Bluetooth, WiFi or other wireless communication modules may be provided by the device interface **220** in order to allow wireless downloading of software, support information or other data, or allow wireless uploading of data to network devices for support, management or other purposes. In some embodiments, Bluetooth, WiFi or other short range wireless communication modules may be used to communicate data to an intermediate device (e.g., a cell phone), which may then communicate the data to a computer or other device at which certain analysis and/or display may be performed. In still other cases, a removable memory device may be used to transfer information from the memory **214** to the removable memory device and thereafter to the remote computer. Thus, in some embodiments, the map data **140** may be communicated to an external computer and may be manipulated thereat, or may be correlated to other map information (e.g., map information from web based mapping services).

In some cases, information may also be uploaded from the remote network terminal or computer to the positioning module **200** and/or the object detection module **202**. For example, upgrading software to improve the functionality of the positioning module **200** and/or the object detection module **202** may be uploaded. In some embodiments, software upgrading user interface capabilities, adding new sensor interface capability, and/or adding other improved functionality may be added via upload in order to upgrade the positioning module **200** and/or the object detection module **202**.

Accordingly, example embodiments may avoid the use of a boundary wire by placing reference objects that are detectable by the robotic mower at one or more locations of a work area. The reference objects may be mapped to map data and may be used to either learn boundaries of the work area (for removal prior to subsequent working of the work area) or assist in defining those boundaries while the robotic mower operates in the work area.

Embodiments of the present invention may therefore be practiced using an apparatus such as the one depicted in FIG. **5**. However, other embodiments may be practiced in connection with a computer program product for performing embodiments of the present invention. As such, for example, each block or step of the flowcharts of FIG. **7**, and combinations of blocks in the flowchart, may be implemented by various means, such as hardware, firmware, processor, circuitry and/or another device associated with execution of software including one or more computer program instructions. Thus, for example, one or more of the procedures described above may be embodied by computer program instructions, which may embody the procedures described above and may be stored by a storage device (e.g., memory **214**) and executed by processing circuitry (e.g., processor **212**).

As will be appreciated, any such stored computer program instructions may be loaded onto a computer or other programmable apparatus (i.e., hardware) to produce a machine, such that the instructions which execute on the computer or other programmable apparatus implement the functions specified in the flowchart block(s) or step(s). These computer program instructions may also be stored in a computer-readable medium comprising memory that may direct a computer or other programmable apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instructions to implement the function specified in the flowchart block(s) or step(s). The computer program instructions may also be loaded onto a computer or other programmable apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block(s) or step(s). In this regard, a method according to example embodiments of the invention may include any or all of the operations shown in FIG. **7**. Moreover, other methods derived from the descriptions provided herein may also be performed responsive to execution of steps associated with such methods by a computer programmed to be transformed into a machine specifically configured to perform such methods.

In an example embodiment, a method for defining boundaries for a work area of a robotic vehicle (e.g., a mower or watering device), as shown in FIG. **7**, may include receiving map data descriptive of a parcel of land at operation **400** and receiving information indicative of at least one reference object disposed on the parcel at operation **410**. The reference object may have corresponding information for defining boundaries for a work area on the parcel associated therewith. The work area may define an area to be worked by a robotic vehicle. The method may further include determining the boundaries responsive to detection of the at least one reference object at operation **420** and operating the robotic vehicle to remain within the area defined by the boundaries at operation **430**.

In an example embodiment, an apparatus for performing the method of FIG. **7** above may comprise a processor (e.g., the processor **212**) configured to perform some or each of the operations (**400-430**) described above. The processor **212** may, for example, be configured to perform the operations (**400-430**) by performing hardware implemented logical functions, executing stored instructions, or executing algorithms for performing each of the operations. Alternatively, the apparatus may comprise means for performing each of the operations described above. In this regard, according to an example embodiment, examples of means for performing operations **400-430** may comprise, for example, the control circuitry **130**. Additionally or alternatively, at least by virtue of the fact that the processor **212** may be configured to control or even be embodied as the control circuitry **130**, the processor **212** and/or a device or circuitry for executing instructions or executing an algorithm for processing information as described above may also form example means for performing operations **400-430**.

In some embodiments, additional optional operations may be included or the operations described above may be modified or augmented. Each of the additional operations, modification or augmentations may be practiced in combination with the operations above and/or in combination with each other. Thus, some, all or none of the additional operations, modification or augmentations described herein may be utilized in some embodiments. In this regard, in some cases, receiving information indicative of the at least one reference object may include detecting the at least one reference object via a sensor disposed on the robotic vehicle. In an example embodiment, detecting the at least one reference object via the sensor may include detecting an invisible marking using the sensor. In some cases, the sensor may be a camera, and detecting the at least one reference object via the sensor may include detecting a visible marking using the camera. In some embodiments, 5 receiving information indicative of the at least one reference object may include detecting one of a plurality of reference objects where each of the reference objects is disposed to define a segment endpoint for a polygonal shaped work area. In an example embodiment, receiving information indicative of the at least one reference object may include detecting an object and determining whether the object is one of a plurality of reference objects based on comparing a characteristic of the object detected to a known characteristic of the reference objects. In some cases, determining the boundaries responsive to detection of the at least one reference object may include identifying the at least one reference object based on unique indicia of the at least one reference object and retrieving the information for defining boundaries for the work area relative to the at least one reference object. In some embodiments, the unique indicia may be associated with a sequential number defining an order of boundary segment endpoints. In some examples, determining the boundaries may further include determining a position of the robotic vehicle relative to the at least one reference object using triangulation or stereo view. In an example embodiment, the unique indicia may be associated with type information indicating a boundary type associated with the at least one reference object. In some cases, the boundary type may be an external boundary or an internal exclusion area boundary. In some cases, any or all of the above modifications may be included and operating the robotic vehicle to remain within the area defined by the boundaries may include directing vehicle operation responsive to repeated detections of the boundaries to avoid the boundaries based on corresponding repeated detections of reference objects. In some embodiments, any or all of the above modifications may be included and operating the robotic vehicle to remain within the area defined by the boundaries may include operating the robotic vehicle to learn boundary locations based on reference object location and, thereafter, operating the robotic vehicle using learned boundary locations subsequent to removal of reference objects. In various example embodiments, the robotic vehicle may be a robotic mower or a watering robot.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe exemplary embodiments in the context of certain exemplary combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. In cases where advantages, benefits or solutions to problems are described herein, it should be appreciated that such advantages, benefits and/or solutions may be applicable to some example embodiments, but not necessarily all example embodiments. Thus, any advantages, benefits or solutions described herein should not be thought of as being critical, required or essential to all embodiments or to that which is claimed herein. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

That which is claimed:

1. A method comprising:

receiving, at processing circuitry associated with a robotic vehicle, map data descriptive of a parcel of land;

receiving, at the processing circuitry, information indicative of at least one reference object disposed on the parcel, the at least one reference object having corresponding information for defining boundaries for a work area on the parcel associated therewith, the work area defining an area to be worked by the robotic vehicle, wherein receiving information indicative of the at least one reference object comprises detecting the at least one reference object via a sensor disposed on the robotic vehicle;

determining, by the processing circuitry, the boundaries responsive to detection of the at least one reference object, wherein the boundaries are defined relative to known locations of the at least one reference object on the parcel of land; and causing, by the processing circuitry, operation of the robotic vehicle only within the area defined by the boundaries, during the automated performance of a yard maintenance task.

2. The method of claim 1, wherein detecting the at least one reference object via the sensor comprises detecting an invisible marking using the sensor.

3. The method of claim 1, wherein the sensor comprises a camera, and wherein detecting the at least one reference object via the sensor comprises detecting a visible marking using the camera.

4. The method of claim 1, wherein receiving information indicative of the at least one reference object comprises detecting one of a plurality of reference objects, each of the reference objects being disposed to define a segment end-point for a polygonal shaped work area.

5. The method of claim 1, wherein receiving information indicative of the at least one reference object comprises detecting an object and determining whether the object is one of a plurality of reference objects based on comparing a characteristic of the object detected to a known characteristic of the reference objects.

6. The method of claim 1, wherein determining the boundaries responsive to detection of the at least one reference object comprises identifying the at least one reference object based on unique indicia of the at least one reference object and retrieving the information for defining boundaries for the work area relative to the at least one reference object.

7. The method of claim 6, wherein the unique indicia is associated with a sequential number defining an order of boundary segment endpoints, or wherein the unique indicia is associated with type information indicating a boundary type associated with the at least one reference object.

8. The method of claim 6, wherein determining the boundaries further includes determining a position of the robotic vehicle relative to the at least one reference object using triangulation or stereo view.

9. The method of claim 6, wherein the boundary type is an external boundary or an internal exclusion area boundary.

10. The method of claim 1, wherein operating the robotic vehicle to remain within the area defined by the boundaries comprises:

directing vehicle operation responsive to repeated detections of the boundaries to avoid the boundaries based on corresponding repeated detections of reference objects; or

operating the robotic vehicle to learn boundary locations based on reference object location and, thereafter, operating the robotic vehicle using learned boundary locations subsequent to removal of reference objects.

11. A robotic vehicle comprising processing circuitry configured to:

receive map data descriptive of a parcel of land;

receive information indicative of at least one reference object disposed on the parcel, the at least one reference object having corresponding information for defining boundaries for a work area on the parcel associated therewith, the work area defining an area to be worked by the robotic vehicle, wherein receiving information indicative of the at least one reference object comprises detecting the at least one reference object via a sensor disposed on the robotic vehicle;

determine the boundaries responsive to detection of the at least one reference object, wherein the boundaries are defined relative to known locations of the at least one reference object on the parcel of land; and

cause operation of the robotic vehicle only within the area defined by the boundaries, during the automated performance of a yard maintenance task.

12. The robotic vehicle of claim 11, wherein detecting the at least one reference object via the sensor comprises detecting an invisible marking using the sensor.

13. The robotic vehicle of claim 11, wherein the sensor comprises a camera, and wherein detecting the at least one reference object via the sensor comprises detecting a visible marking using the camera.

14. The robotic vehicle of claim 11, wherein receiving information indicative of the at least one reference object comprises:

detecting one of a plurality of reference objects, each of the reference objects being disposed to define a segment endpoint for a polygonal shaped work area; or

detecting an object and determining whether the object is one of a plurality of reference objects based on comparing a characteristic of the object detected to a known characteristic of the reference objects.

15. The robotic vehicle of claim 11, wherein determining the boundaries responsive to detection of the at least one reference object comprises identifying the at least one reference object based on unique indicia of the at least one reference object and retrieving the information for defining boundaries for the work area relative to the at least one reference object.

16. The robotic vehicle of claim 15, wherein the unique indicia is associated with a sequential number defining an order of boundary segment endpoints, or wherein the unique indicia is associated with type information indicating a boundary type associated with the at least one reference object.

17. The robotic vehicle of claim 15, wherein determining the boundaries further includes determining a position of the robotic vehicle relative to the at least one reference object using triangulation or stereo view.

18. The robotic vehicle of claim 11, wherein the robotic vehicle is a robotic mower or a watering robot.

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